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TUNING A BELL

Nuclear Science Programs

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the cover

The cover photograph shows Mr. H. T. van Bergen in the process of tuning a bell. The adjustable tuning fork helps him determine the frequencies of the five notes of the bell, and he uses the lathe to modify the shape of the bell until all five notes are in perfect harmony. The details of the van Bergen technique for tuning bells have been passed from father to son for eight generations. For the story of how little bells have been made to sound like big ones, see the article beginning on page 4 of this issue.

Cover Photograph by Cecil Phillips

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"IT IS CHEAPER TO DO THE WORK AGAIN than to find it in the literature," is a statement I have heard several times from men engaged in research and development. They refer to projects involving perhaps many man-weeks of work, yet their charge is not altogether facetious. The current rate of scientific publication is overwhelming.

This information problem is not to be regarded lightly. It not only causes expensive duplication of effort in development work, but it is a bottleneck in one of the most essential aspects of basic research—the dissemination of knowledge.

The most effective approach to this roadblock is the same as to any other important problem. Competent, properly trained personnel must be assigned to cope with it on a full-time basis. Of course, this costs money, and in most cases the return on such an investment cannot be estimated. But in other cases it can greatly affect the competitive position of a firm or even the strength of a nation.

Georgia Tech is actively engaged in information research. The Technical Information Section of the Engineering Experiment Station has a staff of graduate engineers and scientists (several with post-graduate degrees) who devote their full time to retrieving and presenting information from the jungles of technical literature.

Although there are less than a dozen similar groups at research organizations in this country, despairing men in research and development (and also other fields now) may be encouraged by the rapidly growing interest in information research groups, company libraries, and methods of reorganizing, translating and condensing published material. This trend may not yet be growing as fast as the force it is opposing, but there is hope that we will eventually establish more reasonable rapport with our own flow of words, words, words.

E. D. Harrison

President

FOR THE SOUND OF BELLS

by Cecil Phillips
Associate Editor

THE ROLE OF SCIENCE IN MUSIC is a subtle one. Some years ago it was discovered that the flairs at the bell ends of trumpets, tubas and other horns follow very closely the curves of certain mathematical functions, such as parabolas, hyperbolas, and exponential functions. This fact led to better understanding of the sound qualities of various horns. Now modern manufacturers of horns and most other musical instruments make use of scientific and engineering principles in addition to their traditional artistic skills.

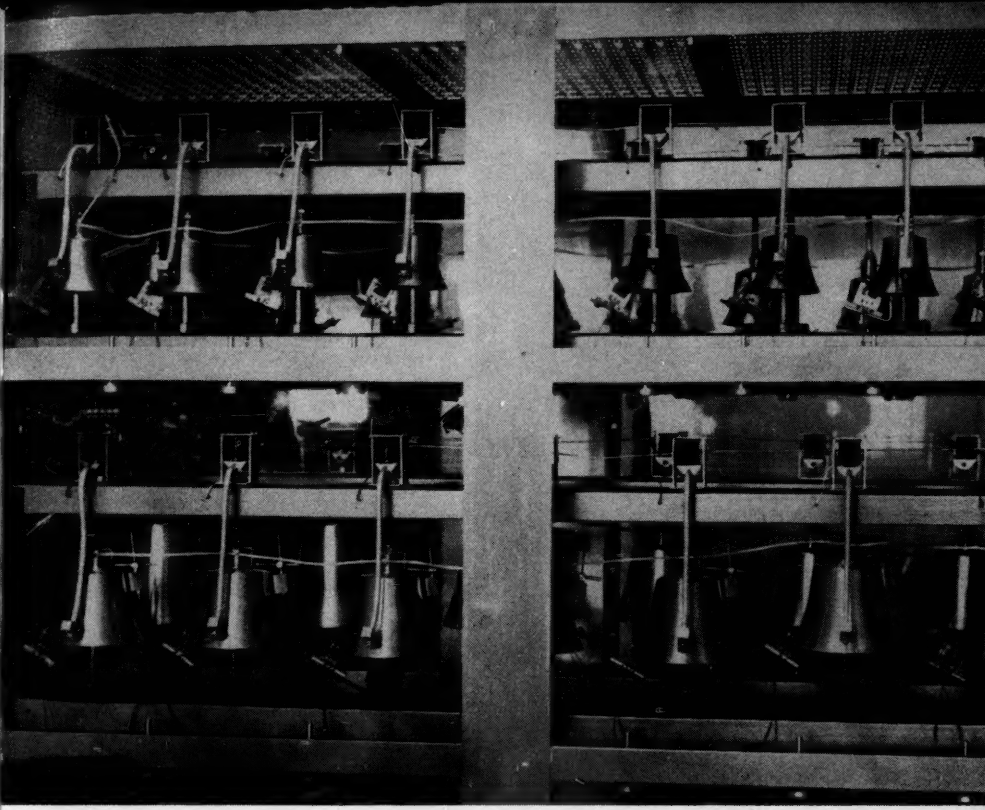
The making of bells, especially tuned ones, is no exception. The process is both an art and a science. The large tuned bells that comprise church carillons are designed on drawing boards before they are cast in metal. The castings are then machined and tuned by artisans who pass on their special techniques from generation to generation. The design and techniques are different among bellmakers, and an expert can easily detect the characteristic sounds that identify the manufacturer.

One such expert, among the very few in the world, is Mr. H. T. van Bergen of Greenwood, South Carolina. Mr. van Bergen is in the seventh generation of the Dutch family that has made tuned bells since 1729. He learned the art of making van Bergen bells at the family's foundry in Heiligerlee, Holland.

Mr. van Bergen first came to the States to install a carillon of bells at the 1939 World's Fair in New York. He also sold two carillon units, one of them to the Callie Self Memorial Church in Greenwood. While he was in Greenwood supervising the installation, World War II broke out. Unable to return to Holland, he and his family remained in Greenwood throughout the war.

When the war was over and the bell industry revived, van Bergen decided to stay in Greenwood and open a foundry there. Since then he has made small hand bells and served as the American representative of the Dutch firm operated by his brothers.

About ten years ago van Bergen began working on the idea of amplifying the



Photographs by Van Toole

This view of the Carillonette shows the bells, the solenoid-operated strikers, and the pick-ups at the lip of each bell. This model has 30 bells, weighing up to three pounds each, which are amplified to sound like large bells weighing several tons.

sound of small bells to make them sound like big bells. The small bronze bells he was making were tuned just like the large bronze bells made in Holland.

They are used primarily as hand bells for choral groups, and the sets are tuned in harmony just as the large carillons are. Why not, he thought, make a carillon of small, much less expensive bells, and amplify their sound electronically?

The idea sounds simple enough in this age of electronic music. But van Bergen did not have in mind a recording device or any approximation to the tones of bells. As a traditional bell maker, only the true sounds of "live" tuned bells would be acceptable. In this respect the artist in van Bergen dominates the engineer (he has a degree in mechanical engineering).

Consequently the problem was not a simple matter of placing microphones in the carillon. For each bell has one dominant note and four other notes, and all five notes are tuned in perfect harmony. The complex harmonics of the bell must remain intact through the amplification or else the timbre of the sound is distorted.

Van Bergen decided to use individual pick-ups on each bell. The pick-up included a small magnetic field, in which a portion of the bell would vibrate when struck. The vibration caused variation in the magnetic flux, which in turn produced

Gas flames swirl up as van Bergen lights the furnace used to melt the bell metal.

a current of electricity that varied proportionately with the bell's vibrations. Such a pick-up device is called a transducer.

There are many ways to wire a transducer, however, and many ways to arrange its geometrical relation to the bell. Over a period of eight years, van Bergen tried a number of pick-up configurations and variations in other components, such as the striking mechanism. In this time, he and his son, Harry, constructed three complete carillons, each with 30 small bells. None of the units was completely free of distortion.

Then on a visit to Atlanta in 1957 a friend gave van Bergen a tour of the Georgia Tech campus, and mentioned the research activities of the Engineering Experiment Station. A few days later van Bergen decided to go back to Georgia Tech and present his problem to the research staff to see what they thought of it.

"They" turned out to be physicists Elmer Rhodes and John Brown, who thought a lot of it. Rhodes and Brown felt that the transducer idea was a good one, but that its optimum arrangement would require detailed analysis. Other components of the system, such as the striking mechanism, also appeared to need refinements in order to obtain the desired accuracy and reliability of the system.

The study was undertaken, and during the following months the halls and laboratories of the Hinman Research Building frequently resounded with the amplified tones of little bells.

Rhodes and Brown approached the problem both analytically and experimentally. Mathematical analysis of the bell as a sound resonator and radiator indicated that the lip of the bell was the best location for the pick-up. It was also found that the bell should be struck at a point 90 degrees from the pick-up so that the slight motion of the bell caused by the strike would not interfere with the variations of flux in the transducer.

A further refinement on the striker consisted of reversing van Bergen's method of using a solenoid to force the striker against the bell. Placing more faith in the consistency of the acceleration of gravity than in the consistency of solenoids, Rhodes and Brown redesigned the mechanism so that the striker was allowed to fall against the bell rather than being forced against it.

Van Bergen's pick-up design was modified in several ways. His original transducer was a variable reluctance type in which the motion of a small, soft iron slug in the bell lip caused flux changes in a soft iron core magnetic circuit. The Georgia Tech design utilizes Helmholtz coils (named for a pioneer in the scientific study of sound and musical instruments) with no iron, and the magnet is placed on the bell rather than the stationary part of the transducer.

The geometry of the pick-up was also rearranged so that the vibrations of the bell are more nearly perpendicular to the lines of flux, thus producing the varia-

tions in current more accurately and efficiently.

The result of these refinements was that the distortion problem was eliminated. Van Bergen and his son incorporated the changes as they constructed a fourth model of the unit, which they call a Carillonette. The amplified sound of the bells is "100 per cent perfect" according to van Bergen, who hopes to sell the instrument to churches, universities and public buildings that do not have bell towers or cannot afford the expense of large bells.*

The small bells, which weigh one to three pounds, have almost the same depth of tone as the large bells, some of which weigh 15 - 20 tons. Yet the Carillonette can be made at about a quarter of the cost of a full sized carillon with the same number of bells.

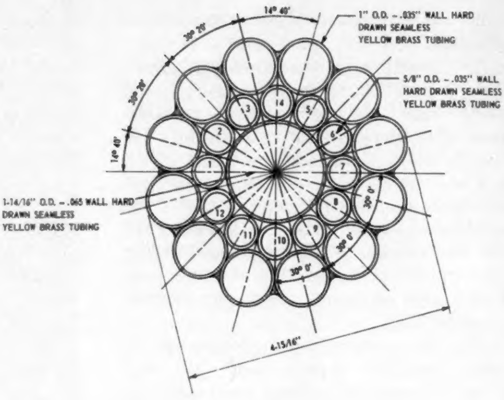
The Carillonette also has many unique features as a musical instrument. Its keyboard is identical in form to that of a piano and may be played the same way. The fact that the bells are tuned in perfect harmony allows chords to be played. The keyboard and bell cabinet may be placed anywhere in the building, either together or separately since their connections are entirely electrical. The array of bronze bells may also be used to decorative advantage in the building.

But above all, as Harry van Bergen likes to say, "They sound like bells for they are bells." The basic sound comes from bells tuned by the traditional van Bergen technique, bells whose tones and quality are accurately enlarged by the application of modern science and engineering.

*To the best knowledge of the editors, there are no tuned, cast bell carillons in the State of Georgia.

The entire staff of the foundry in Greenwood, H. T. van Bergen and his son, Harry, pose around the keyboard of the Carillonette, which can be played like a piano.

The Cesium Irradiator



A HIGH INTENSITY gamma-ray irradiator has been installed in the Radioisotopes and Bioengineering Laboratory at Georgia Tech.

This installation was developed in cooperation with the Office of Isotopes Development, U. S. Atomic Energy Commission, to facilitate research in the area of isotopes technology.

The irradiator is of the Notre Dame cobalt-60 type with 12 sources of cesium-137 of approximately 1,000 curies each. A horizontal cross section of the tube nest is shown above. Cs-137 was selected as the active material because: (1) Cs-137 has a 30-year half-life, compared to 5.3 for Co-60, and (2) calculations indicated that, for the same range of specific activity, the total dose rate from the Cs-137 sources would be comparable to that from Co-60.

Dosimetry studies have been performed in the source, and dose rates of 1.4 x 10^6 rad/hr. in the center sample hole and 1.0 x 10^6 rad/hr. in the outer holes have been obtained. The radiation field is homogeneous through a vertical movement of 4 inches. The energy yield of the irradiator is in the same range as some of the existing Co-60 installations.

The research irradiator has already been put to work on an industrial problem—increasing the amount of high-grade industrial kaolin that can be obtained from Georgia's vast kaolin deposits.

The mineral kaolinite is the primary constituent of Georgia kaolin. A discrete kaolinite particle appears as a hexagonal, thin flat plate. These particles normally occur in the colloidal size range and it is this property along with their platelike structure that gives kaolin some of its most desirable properties. Frequently, however, kaolin contains stacks of these plates that appear as particles ranging in size from 2 to 40 microns or more. The presence of these stacks in any appreciable quantity renders the clay unsuitable for some of its most important applications, such as paper coating and filler in automobile tires.

The researchers in the Station's Micromeritics Branch recognized that high-energy, ionizing radiation could bring about the degradation of chemical bonds in both organic and inorganic solids, so a project was begun to determine whether or not gamma-radiation from the research irradiator could bring about the deagglomeration of kaolin stacks. The results to date indicate that discrete kaolinite plates can be obtained from stacks when they are subjected to high-energy, ionizing radiation. Future investigations will be concerned with evaluating the use of high-energy, ionizing radiation in conjunction with normal size reduction methods.

Reactor Progress

by William H. Harrison, III
Director, Reactor Project

TO THOSE WHO HAVE KNOWN of the Reactor Project from its beginning, it must seem like the egg which never quite gets hatched. This progress report is presented so as to give renewed hope that, though the egg has not yet hatched, it surely won't be long until the hatching process begins.

Briefly, the past may be reviewed by noting certain key events. The final report of the Reactor Subcommittee of the campus-wide Nuclear Science Committee was submitted in July, 1956. In this report, it was recommended that a research reactor of extensive capability should be considered as a goal for Georgia Tech. Very soon thereafter, the Reactor Project was organized, under the administrative direction of Dr. J. E. Boyd, Director of the Engineering Experiment Station. A contract was negotiated with Dr. Walter Zinn (recent co-winner of the $75,000 Atoms for Peace Award) for the preparation of the conceptual design of a research reactor for Georgia Tech by his company, General Nuclear Engineering Corporation. By September, 1957, the conceptual design was completed and rough estimates were made concerning costs of the projected facilities.

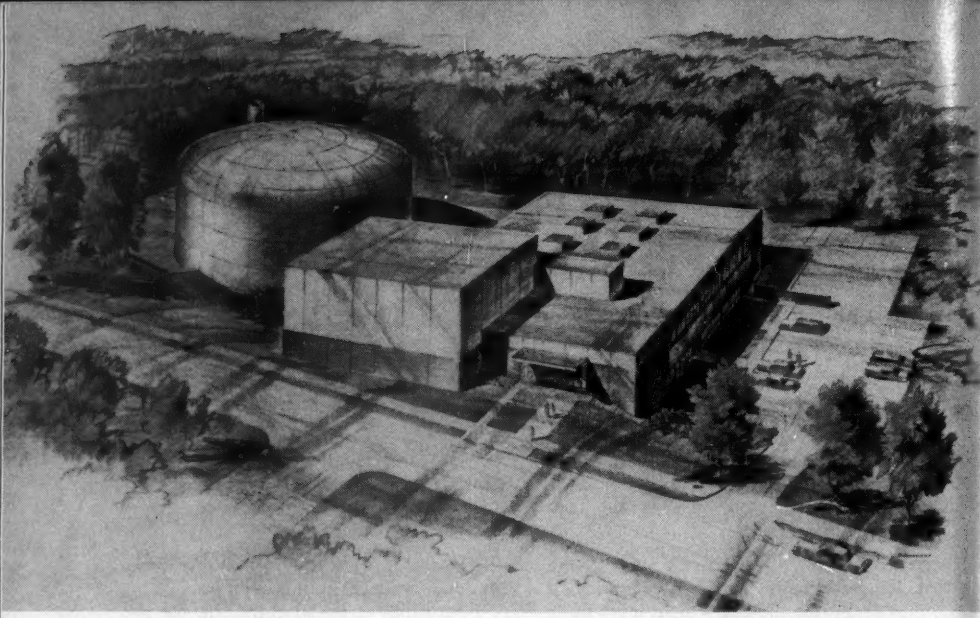
The really big events in the funding picture came about August, 1957, with Governor Marvin Griffin's special appropriation of $2,500,000, and in February, 1959, with a grant of $750,000 from the National Science Foundation.

Following the initial grant, the site was selected and purchased for the project. Commitments were made to General Nuclear Engineering Corporation for preparation of the detailed design of the reactor, and to Robert and Company Associates for the detailed design of the reactor building and the supporting offices and laboratories. At the present time, the design work is completed and the contract documents are essentially ready for construction bidders.

On the first day of February, 1960, formal application was made to the Atomic Energy Commission for a construction permit. This permit should be in hand sometime in June, at which time the invitations to bid on the project will be issued to interested construction firms.

It has been decided that the reactor facilities will be called the Nuclear Research Center. An artist's conception of how these facilities will look is shown on the next page. The reactor site consists of an area of about two acres along the western edge of the present campus. (The site is west of Atlantic Drive, N. W., at the end of Eighth Street.)

The nuclear reactor which will serve as the key component of the Nuclear Research Center is a heterogeneous, heavy



RESEARCH REACTOR IS LARGEST PROJECT IN GEORGIA TECH'S HISTORY.

water moderated and cooled machine, fueled with highly enriched plates of aluminum-uranium alloy. It is designed to produce a thermal neutron flux of more than 10^{13} $n/cm^2/sec$ at a power of one megawatt and an average moderator temperature of 100°F. A section through the reactor is shown on the facing page.

The fully loaded reactor core is 2 feet in diameter, 2 feet high and contains 19 fuel assemblies of 10 plates each, spaced 6 inches apart in a triangular array. The total uranium-235 content of this loading is 2.7 Kg. The fuel is centrally located in a 6-foot diameter aluminum reactor vessel which provides a 2-foot thick D_2O reflector completely surrounding the core.

The reactor vessel is mounted on a steel support structure and is suspended within a thick-walled graphite cup. The graphite provides an additional 2 feet of reflector both radially and beneath the vessel. The core and reflector system is completely enclosed by the lead and concrete biological shield.

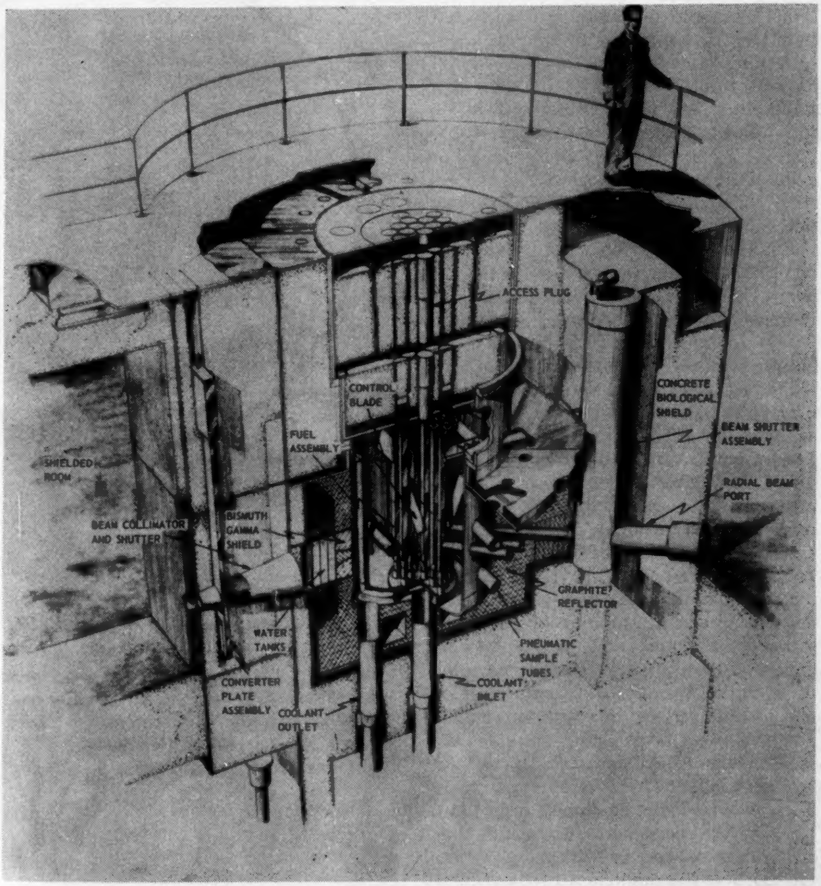
The reactor is controlled by means of four cadmium shim-safety semaphore blades and one cadmium regulating rod. The four shim-safety blades are mounted at the top of the reactor vessel and swing downward through the core between adjacent rows of fuel assemblies. The regulating rod is supported on the reactor top shield and extends downward into the radial D_2O reflector region. The rod moves vertically between the horizontal center line and the top of the core.

The reactor is provided with a heat removal system, D_2O purification system, shield cooling system, D_2O storage system, radiolytic gas recombination system and ventilating system. The heat removal system is composed of a primary heavy water system and a secondary light water system. The heavy water system contains the reactor vessel, the primary D_2O coolant pumps, the D_2O makeup pump, the heat exchanger and the associated valves and piping. All components in contact with the D_2O are fabricated of stainless steel or aluminum. The light water secondary system is composed of the circulating water pumps, the cooling tower, water treatment equipment and the as-

sociated valves and piping. The secondary coolant system is fabricated of carbon steel.

Since the reactor is intended for research applications, a variety of experimental facilities are incorporated which provide for a wide range of research investigations. The design includes ten horizontal radial beam tubes, two horizontal tangent tubes, two horizontal pneumatic rabbit tubes, two horizontal irradiation tunnels, twenty-nine vertical irradiation thimbles and two vertical fast flux tubes. In addition, the reactor face contains a thermal column and provisions for the installation of a collimator and shutter for irradiations in a shielded room.

The location of the reactor in the containment building and the relationship between various laboratories and offices may be seen in the first floor plan. The Reactor Containment Building is eighty feet in diameter and sixty-five feet in height. The building will have three levels. The basement will contain process



Cutaway view shows the arrangement of the reactor core within the graphite reflector and biological shield. Shielded room at left is primarily for medical research.

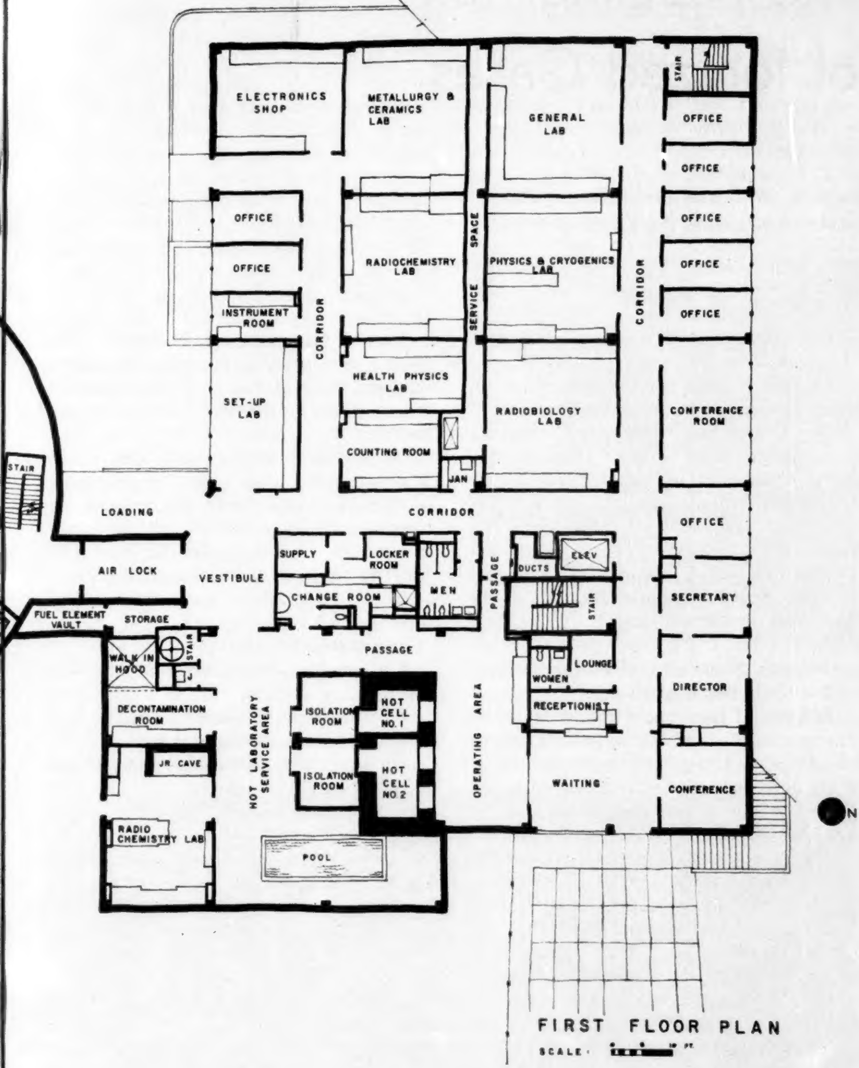
and ventilating equipment. The main floor is largely unobstructed and will provide space for installation of experimental equipment.

The control room will be located on a balcony at the level of the top of the biological shield. The main floor and reactor top will be serviced by a twenty-ton capacity polar crane. During reactor operation, access to the building will be restricted to an air lock connected to the adjoining Laboratory and Office Building and to an air lock leading to the outside. When the reactor is not operating, additional access to the building is provided by a large truck entrance.

Among the facilities in the 24,000 square feet, two-story air-conditioned Laboratory and Office Building will be the following: Two 50,000-curie capacity (at a gamma energy of 1 Mev) hot cells equipped with mechanical master-slave manipulators; fuel element storage and handling pool connected to one of the hot cells; high level raidochemistry laboratory containing two 10-curie capacity junior caves, glove boxes and radioisotope hoods; separate decontamination room; change room isolating the above facilities from the remainder of the building; counting room; set-up laboratory for final assembly and testing of experimental equipment prior to installation in the hot cells or reactor; laboratories for low level chemistry, health physics, ceramics, metallurgy, physics, cryogenics, radiobiology and electronics; facilities for disposal of solid and liquid radioactive wastes and a "hot" laundry; medical suite including two patient rooms and two laboratories; dark room, machine shop; large animal area; and a viewing gallery for visitors to allow observation of activities within the reactor building and hot cell service area without actually entering either area.

With these facilities, construction of which should start this summer, Georgia Tech will be better equipped for certain types of advanced nuclear research than any other college or university in the United States. Completion of these facilities will truly represent a giant step forward for Georgia Tech and the South.

The first floor plan shows that a common service space is accessible from several major laboratories. This feature has proved to be very desirable in Georgia Tech's Radioisotopes and Bioengineering Laboratory.



FIRST FLOOR PLAN

SCALE

The Puzzling Role of Ionized Gases

by E. W. McDaniel and D. W. Martin
Research Associate Professors of Physics

THE DISCOVERY OF X-RAYS IN 1895 marked the beginning of the quantitative study of gaseous ions and electrical discharges in gases. Accordingly gaseous electronics, to use the term now applied to encompass these subjects, is one of the oldest branches of modern physics.

Literally thousands of experiments have been performed to study the structure and properties of gaseous ions and to elucidate their role in electrical discharges. These investigations have made important contributions to the growth of physics, both in the development of experimental apparatus and techniques and in the formulation of modern theory.

In spite of the concentration of effort in this area for over half a century, many of the long-recognized problems have been only partially solved. In addition, recent studies of atmospheric and astrophysical phenomena have revealed that ionized gases play a much more important role in nature than was previously realized, and present knowledge is insufficient to explain many of the observations.

Finally, it may be pointed out that the world's energy resources, including fissionable materials, are expected to be exhausted within a few centuries. The development of techniques for the controlled fusion of the heavier isotopes of hydrogen (deuterium and tritium) in new and highly unconventional types of discharges appears to offer the greatest hope for the long-range solution of our fuel problem.

These considerations explain the continuing and growing interest in gaseous ions and the fact that gaseous electronics is one of the most active fields in physics today.

As implied above, gaseous electronics is concerned, partly with the properties of ions and the basic phenomena involving ions, and partly with the study of gaseous discharges. In the first category we may list the following topics:

a. the formation and structure of positive and negative ions,

b. charge transfer,

c. the diffusion of electrons and ions in gases,

d. the recombination of positive ions with electrons and negative ions,

e. the energy distributions of charged particles in electric fields,

f. the drift velocity of ions and electrons in electric fields,

g. reactions between ions and molecules resulting in the formation of new species,

h. the interaction of charged and neutral particles with surfaces, and

i. the emission and absorption of electromagnetic radiation by ions, atoms, and molecules.

Several of the above phenomena are now being studied experimentally at Georgia Tech in the new Radioisotopes and Bioengineering Laboratory.

High-Energy Study

One of our research programs deals with ionization and charge transfer pro-

duced by high-energy hydrogen ions moving through hydrogen gas. This experiment constitutes the Ph.D. Thesis problem of Mr. John Hooper, a graduate student and instructor in the School of Electrical Engineering.

The work is supported by the Thermonuclear Branch of the Atomic Energy Commission and should yield data useful in the design of certain types of experimental fusion reactors. These particular devices utilize energetic beams of hydrogen ions to ionize hydrogen gas with the goal of initiating a special type of discharge in which the ions are swarming about with sufficiently high velocity to enable them to undergo nuclear fusion. When the nuclei of two hydrogen ions fuse, millions of times as much energy is released as is provided by the chemical combustion of a molecule of conventional fuel. This fact, considered along with the practically inexhaustible supply of hydrogen in the oceans, accounts for the great interest in developing fusion reactors.

An important consideration in the design of the type of device under discussion here is the "cross section" for ionization of hydrogen molecules by incident hydrogen ions. This quantity is proportional to the average number of ions produced in the gas by each projectile and is one of the factors involved in the establishment of the required discharge.

Equally important is knowledge of the cross section for charge transfer between a given projectile ion and a target particle. The mechanism involved here is the transfer of an electron from the struck gas particle to the projectile ion, resulting in the neutralization of the ion and the acquisition of a positive charge

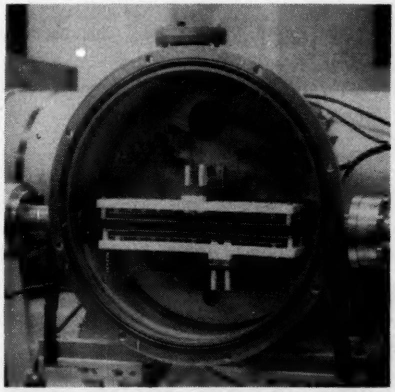
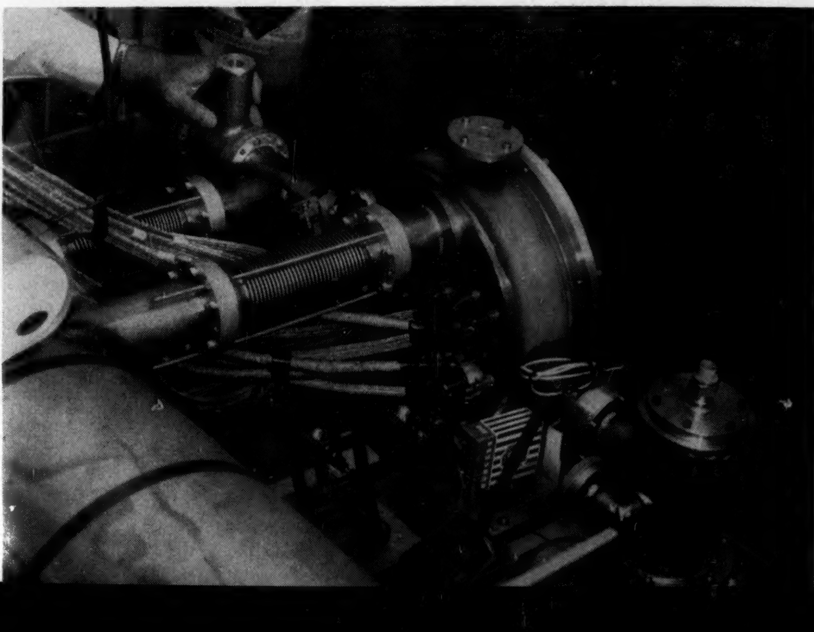


Figure 2. Interior of the collision chamber used in high-energy ionization studies.

Photographs by Van Toole

Figure 1. Back view of the collision chamber shows part of the associated vacuum and electrical systems. The beam tube at upper left brings in particles from Van de Graaff.



by the target particle. This is a very undesirable effect, since not only must we have a large number of hydrogen ions swarming about in the device but also the ions must have quite high energies. When charge transfer occurs, we are left at best with a "cold" hydrogen ion in place of the original "hot" ion, or at worst with a "cold" ion of some impurity such as carbon which will continually degrade the discharge until it is swept out.

Our cross section experiment involves the injection of a beam of hydrogen ions into a collision chamber which is filled with hydrogen gas at a low pressure (10^{-3} to 10^{-4} mm Hg). We measure the fraction of the particles which produce an ion-pair in the gas and also determine the fraction which experience charge transfer. The Van de Graaff accelerator (see page 20) provides the beam of incident ions. These ions, whose energy is continuously variable from 0.15 to 1.1 million electron volts, pass through the Van de Graaff analyzing magnet and a system of slits and apertures into the collision chamber in which the ionization and charge transfer events take place.

Figure 1 shows the collision chamber, while Figure 2 provides an over-all view of the chamber and the associated gas-handling apparatus.

As a matter of convenience this experiment is being performed with ordinary, or light, hydrogen rather than deuterium or tritium, the two heavier isotopes of hydrogen which can undergo fusion with appreciable probability and which will eventually serve as the fuel for fusion reactors. The cross sections of interest here have been shown to be almost exactly the same for ions of different isotopic form moving with the same velocity, so the data obtained with the lighter particles provide the desired information regarding the heavier.

Low-Energy Study

The second experiment to be described here involves a study of the reactions which occur between low-energy gaseous ions and molecules. Examples of these reactions are clustering, dissociation,

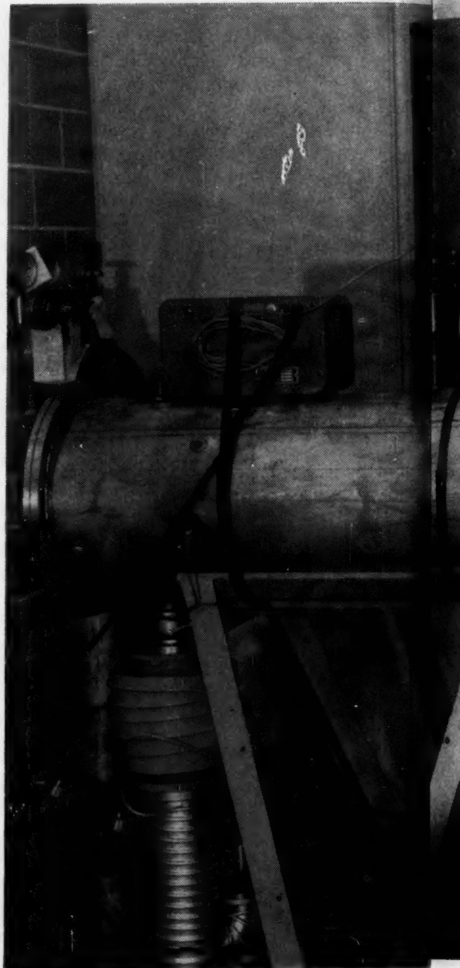
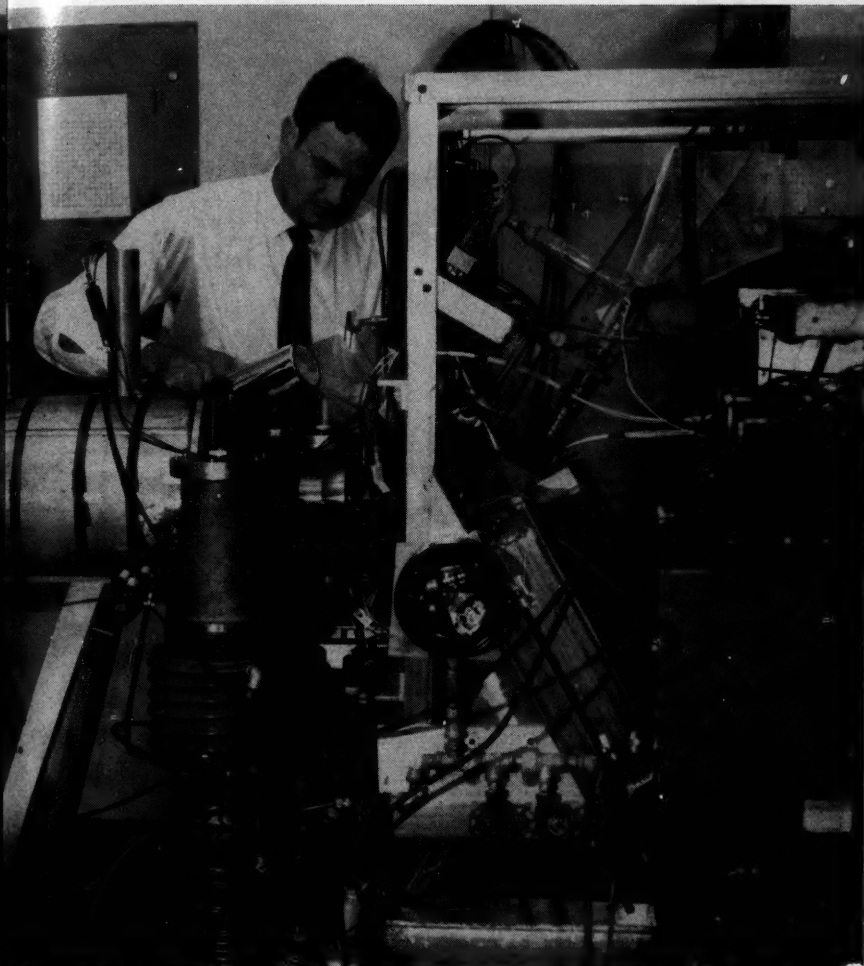


FIG. 3. DR. McDANIEL IS SHOWN

charge transfer, and chemical combination, and such reactions play an important role in gas-filled radiation detectors, ion sources, and atmospheric phenomena.

The apparatus used in this experiment is shown in Figure 3. The horizontal tube on the left is a drift tube, the apparatus on the right is a mass spectrometer, while the central section is a differential pump-



WITH DRIFT TUBE APPARATUS HE BUILT FOR ION-MOLECULE STUDIES.

ing chamber. Ions are produced in a thermionic source located inside the drift tube which contains gas at a pressure of 0.01-0.50 mm Hg. The ions drift down the tube under the influence of a weak electric field and pass through a small aperture at the end into the field-free two-stage differential pumping chamber. From the second stage of this chamber the ions enter a 60-degree magnetic deflection mass spectrometer.

The number of ion-molecule collisions in the drift tube may be varied over a wide range by moving the ion source along the axis of the tube and by changing the drift tube pressure, and reaction cross sections are determined from the resulting changes in mass spectra.

The polished shell at left fits over the top of the Van de Graaff assembly forming the high-voltage terminal. The beam passes through ribbed column to room below.

Georgia Tech's Atomic Gun

by D. W. Martin and E. W. McDaniel
Research Associate Professors of Physics

ONE OF THE DEVICES often constructed by energetic high-school physics students is a small Van de Graaff generator, a machine that can produce high voltages and long sparks, or "lightning bolts." Large-scale models of the machine are far from mere demonstrators of electrical principles, however. Equipped to function as particle accelerators they are powerful tools for education and research in several fields, particularly nuclear physics.

One of the major items of equipment used in Georgia Tech's nuclear programs is a one-million-volt Van de Graaff positive ion accelerator. This machine was purchased by the School of Physics with the help of a grant under the Educational Assistance Program of the Division of Reactor Development, U. S. Atomic Energy Commission. The accelerator was made by the High Voltage Engineering Corporation and installed in mid-1959. It is now in regular use in graduate courses in neutron and reactor physics of Tech's Nuclear Science and Engineering Program. It also provides energetic ions for research in ion cross sections (see page 16).

The machine is installed in a specially designed facility in the new Radioisotopes and Bioengineering Laboratory. A con-

crete penthouse on the roof of the building houses the accelerator proper, with a "target room" on the ground floor below. To provide for radiation protection, a semi-permanent block wall 16 inches thick separates the target area from the rest of the neutron laboratory, and the other three sides of the target room are of concrete 12 inches thick. Operation is conducted remotely from a control center outside the wall. The penthouse walls will provide radiation protection for adjacent areas in the event that additional floors should be added to the present one-story structure.

The name "Van de Graaff" designates a particular type of electrostatic accelerator. An electrostatic accelerator has a highly insulated terminal and a means of maintaining the terminal at a very high static potential with respect to ground. An insulated and evacuated "acceleration tube" extends from this terminal to ground. An ion injected into the high-potential end of the tube is accelerated to ground by the electrostatic field, acquiring a kinetic energy proportional to its charge and to the potential of the terminal.

In a Van de Graaff the terminal potential is maintained by carrying charge to the terminal mechanically. An endless rubber belt runs over two pulleys, one located at ground, and the other inside the hollow terminal structure. Charge is "sprayed" on the belt at the ground end by an array of pointed electrodes connected to a voltage supply. The moving belt carries the charge against the potential gradient up to and into the terminal, where there is no field due to the already existing potential of the terminal. The charges on the belt still repel one another, however, so a second array of pointed electrodes readily "wipe" the charge from the belt surface and deposit it on the terminal. In our machine a continuous current of about 170 micro-amperes is carried on a belt 6 inches wide, running at a linear speed of about 40 feet per second.

The limiting voltage attainable by this means is governed primarily by the extent of the insulation between the terminal and ground. The terminal is supported by a "column" composed of a cemented stack of metal disks (equipotential planes) separated axially by glass spacers. The acceleration tube is similarly constructed, and both it and the belt extend to the terminal through axial "tunnels" inside the column. Several lucite rods also extend to the terminal through other tunnels, to provide for external control of components inside the terminal. The entire column and terminal assembly is enclosed in a steel tank filled to 200 psig with a mixture of dried nitrogen and carbon dioxide.

In our machine the dimensions and construction of the column and tank provide a nominal rating of one million volts, and will actually stand about 1.25 mega-volts before sparking occurs. Thus singly-charged ions can be accelerated to energies of greater than one Mev (Million- electron-volts). By greatly increasing the dimensions and cost, single-stage machines of this kind are currently built with ratings up to about 6.5 megavolts.

The Van de Graaff was one of the earliest types of accelerators to be developed, and the ion energies attainable are rather low compared to several later types of accelerators, such as the cyclotron or the synchrotron. Nevertheless it continues to be of importance because, if the static potential of the terminal is carefully stabilized, each ion in the beam will be given the same acceleration as every other ion to a precision far greater than can be achieved with most other accelerator types. This superior energy uniformity or "resolution" is of crucial importance in some applications. The energy spread in the beam from our machine is only about 0.002 Mev, which is 0.2 percent at 1 Mev.

Since the Tech Van de Graaff is a positive-ion accelerator, the terminal has a positive potential. It contains a positive-ion source that can provide a continuous ion current of up to 70 micro-amperes. With hydrogen as the source gas, this current is about two-thirds protons (H^+ ions) and one-third molecular ions (H_2^+). We are currently using a mixture of ordinary and heavy hydrogen (deu-

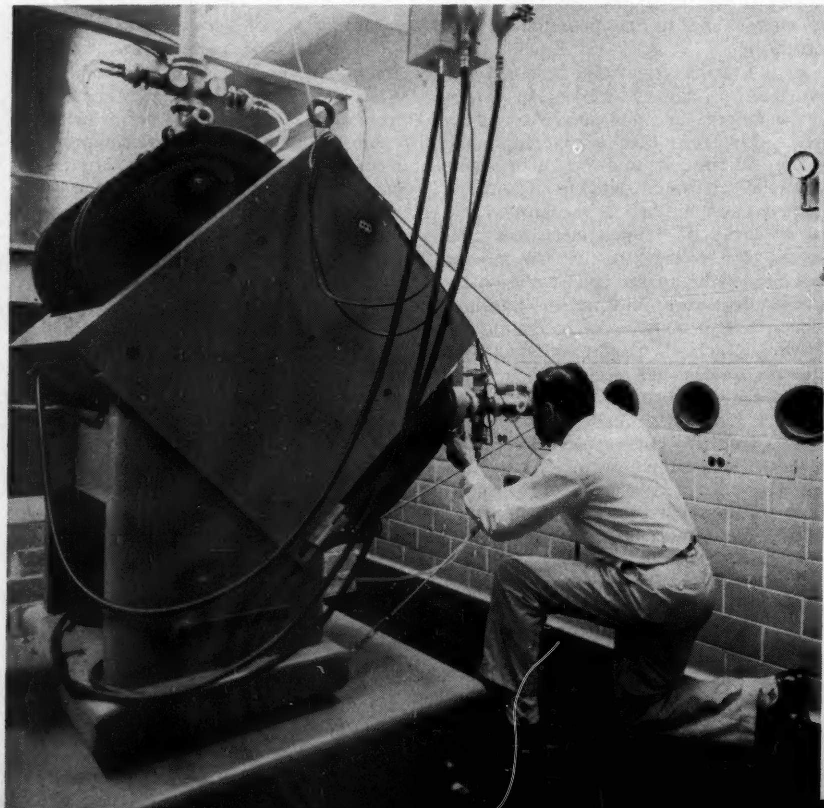
terium) so that the beam contains about 25 micro-amperes each of protons and deuterons, together with lesser amounts of the molecular ions H_2^+, HD^+, and D_2^+.

The beam emerges vertically from the bottom of the machine and passes through an evacuated tube into the target room below, where it is deflected 90° into a horizontal path by a large electromagnet. By varying the magnetic field we can direct to the exit portal at will either the mass-1 beam of protons or the mass-2 beam of deuterons (and H_2^+ ions). The magnet can be rotated about a vertical axis, so that the emerging beam can be directed to any azimuth. It may be directed through any of several ports in the target-room wall into the adjacent physics laboratory (where the ion cross-section experiment is located).

The terminal of our Van de Graaff also contains components to provide the option of an intermittant or pulsed beam instead of the normal steady current. The length of the burst may be varied from around 20 to more than 400 microseconds, with a repetition rate variable from 200 to 6,400 pulses per second. The total switching time from beam-off to beam-on or vice versa is less than 5 microseconds. The usefulness of this feature is indicated below.

Historically, accelerators have been largely identified with nuclear physics and nuclear chemistry. The positive hydrogen ion is actually a bare nucleus called a proton, which is one of the building blocks of all heavier nuclei. Bombardment of a target with protons or other light nuclei can produce "nuclear reactions," in which the incident particles enter and merge with target nuclei, forming new and heavier nuclei in highly excited states. Such a nucleus may dispose of its excess energy either by emitting gamma rays or by emitting one or more of its constituent particles. If the emitted particle is not the same as the incident particle, the constitution of

LARGE MAGNET TURNS BEAM FROM VERTICAL TO ANY OF THE WALL PORTS.



the residual nucleus is different from that of the original target nucleus, and a "transmutation" has occurred.

A large part of experimental nuclear physics has consisted of detailed studies of accelerator-induced reactions. Often the residual nucleus is radioactive, and accelerator bombardment is sometimes used simply as a means of producing a desired radioactivity. Often the emitted particles or the gamma rays are themselves the things of principal interest. Thus, for example, an accelerator-induced reaction that yields a neutron is often used to provide a source of neutrons for some other experiment.

Only a few nuclear reactions in targets of low atomic number can be produced with an appreciable yield at the modest bombarding energies of our accelerator. Most of these have already been studied in great detail, and so further reaction studies do not offer likely prospects for new research. Spectrometric studies of some of the short-lived radioactivities that these reactions produce are a possibility that has not yet been fully explored.

However, among the available reactions there are several that give a substantial yield of neutrons, and it is as a neutron source that we are using the Van de Graaff in the courses in neutron and reactor physics. When our 25-microampere mixed beam of deuterons and H_2^+ ions is incident at 1 Mev on a target of beryllium metal, an estimated 2×10^9 fast neutrons per second are produced by the reaction

$$Be^9 + d \rightarrow B^{10} + n + \text{energy}.$$

This is several hundred times as many as are produced by the largest polonium-beryllium sources that are ordinarily available.

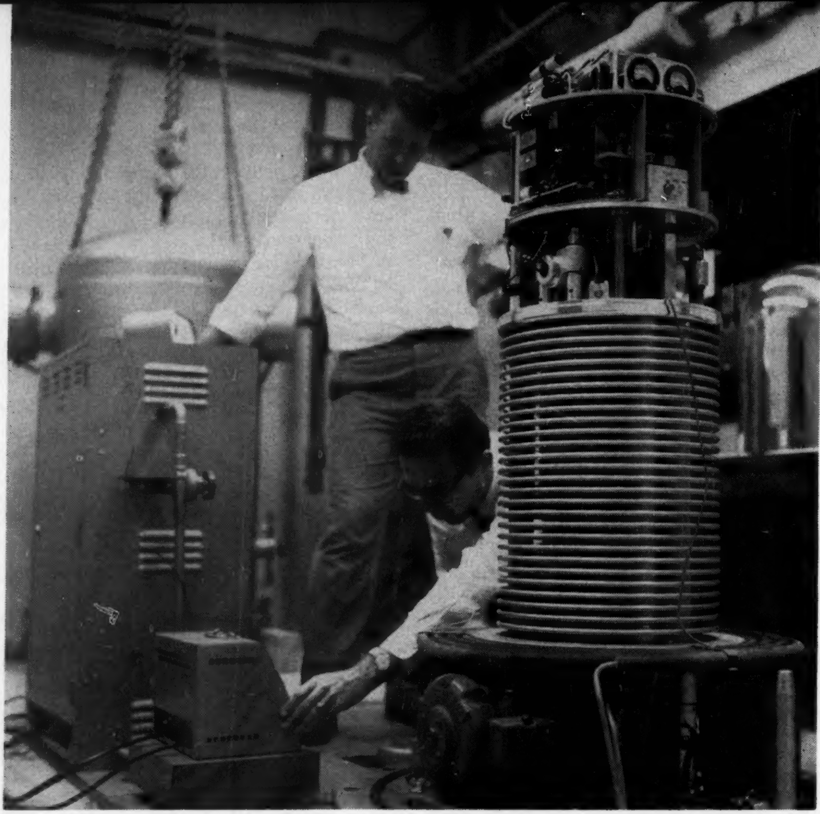
The tank of the Georgia Tech subcritical reactor (used for instruction) is located in the Van de Graaff target room. The beryllium target can be placed inside the tank, on the vertical axis near the bottom. When the tank is filled with water, the fast neutrons are slowed to thermal energies, and then they diffuse in the water until they either leak out or are captured. A number of experiments are performed by the students in these courses to evaluate the slowing and diffusing parameters of water. Spatial mapping of the neutron flux when the natural uranium fuel rods are suspended in the tank permits evaluation of the multiplying properties of the natural uranium—ordinary water system.

The "steady state" experiments described above would be the same whether the neutron source was the Van de Graaff or the polonium-beryllium source that was previously used, except for the greater intensity now available. However, the pulsed capability of the Van de Graaff makes available a whole new class of time-dependent or transient experiments. These experiments provide easier and often better ways of measuring some of the same quantities, and many additional details of the slowing and leakage of neutrons also become accessable to observation.

In these experiments, the neutron counting rate at some fixed location is analyzed as a function of time during the interval between bursts of the intermittant source, using a 20-channel time sorter that is synchronized with the beam pulse. A small group of students is currently exploring some of the experimental possibilities in this area as a graduate level Special Problem course.

We are presently constructing a small general purpose thermal neutron irradiator to use with the Van de Graaff. A mass of paraffin about one cubic foot in size will surround the beryllium target, and will have a thimble for positioning a small sample within the mass near the target. The thermal neutron flux at the sample position will be of the order of 10^7 neutrons per square centimeter per second. This facility will first be used for the rapid determination of the cement content of concrete samples by activation analysis for calcium-49 (a project directed by Dr. Donald Covault). A number of other applications of this irradiator are anticipated in the future.

In the ion cross section studies mentioned briefly at the beginning of this article, the proton beam from the Van de Graaff is passed directly into the collision



In this view the charging-belt drivemotor is visible at the bottom, and the top pulley can be seen inside the terminal structure. Pressure tank is on hoist in rear.

chamber of the cross section apparatus. The processes under study in this case do not involve nuclear reactions, but rather atomic and molecular reactions. (Details are presented in the article on page 16).

Other types of accelerators that produce much higher energies have a number of applications that are not accessable to our Van de Graaff. For example, when the very-high-energy (up to several thousand Mev) protons from a large modern synchrotron bombard a target, a different kind of sub-nuclear reaction may occur in which several kinds of unstable particles called mesons, hyperons, "strange particles," and anti-particles are produced. Observations of these events relate to the most fundamental questions of the nature of matter and energy.

Negative-ion (electron) accelerators have still other uses. The electron beam may be used to produce ionization in a sample by direct bombardment. This technique is of use in solid state physics, in radiation chemistry, in certain biological studies, and is even used on a commercial scale for sterilization of surgical supplies, packaged foods, and medicines. Alternatively, if a metal target of high atomic number is bombarded with electrons, high-energy X-rays are produced that have such diverse applications as radiography and cancer therapy. With very high energy electrons, both the electron beam itself and the X-rays that it can produce find application in nuclear physics.

Ross, Lawrence W., "The Information Problem." Reprinted from Chemical Engineering, March 21, 1960. Reprint 146. Gratis.

The overabundance of technical information tends to smother its usefulness. At the same time, engineers need information as never before. This dilemma, known as The Information Problem, can be solved by planning. Aspects of a typical information plan—including the nature of information, information needs of engineers, and alternatives for sources of information—are discussed.

"Quality Research for a Quality Industry," published by the A. French Textile School and the Engineering Experiment Station, 1960. Gratis.

Research on modern textile problems requires a staff of experienced textile specialists and strong supporting facilities. This eight-page illustrated brochure describes Georgia Tech's capability to meet these requirements in research on textile materials, processes, and machinery, from small investigations through pilot plant operations.

Ideas, Industrial Development at Georgia Tech, Kenneth C. Wagner and Robert B. Wallace, editors, Vol. 2, No. 1, March-April, 1960. Gratis.

"Little Known Facts About Georgia's Economy" is the subject of this issue. Accurate figures show that manufacturing has been the State's No. 1 employer since 1949. In 1959 over 27.5% of the State's workers drew their pay in manufacturing plants, while 9% earned their living principally in farming. The lack of new jobs, however, is cited as a major cause of Georgia's decline in population growth rate. The need for new industrial plants of various types is proposed as one of the State's most important economic problems.

Physiography and Climatology of the Atlanta Area, An Excerpt from the Safeguards Report for the Georgia Tech Research Reactor, Edited by Carlyle J. Roberts. 1960. Bulletin 24. Gratis.

In preparing a safeguards report for the U. S. Atomic Energy Commission, much general information on the Atlanta area was collected and compiled. This information has been extracted from the report and published as a Bulletin of the Engineering Experiment Station. It consists of 40 pages of data on topography, drainage, geology, hydrology, meteorology, seismology and other subjects. Included are wind roses for various altitudes and seasons; temperature and precipitation charts; map of North Georgia drainage basins; and other miscellaneous facts such as the tornado and earthquake records of the Atlanta area.

Blakely, C. E., and R. N. Bailey, "Making Transmitters RFI-Free," Reprinted from Electronics Industries, Vol. 19, No. 3, March 1960. Reprint 144. Gratis.

If all the signal sources inside the transmitter are known then the frequencies at which the interference will appear can be calculated by rather simple linear equations. It is somewhat more difficult to calculate amplitudes, because these depend on nonlinearities. Other methods must be used.

These publications and the complete list of technical publications may be obtained by writing Publications Services, Engineering Experiment Station, Georgia Institute of Technology, Atlanta 13, Georgia.

Edited in Retrospect

cross reference

• President Harrison makes reference in this issue to the "information problem," which is also the title of an article listed on the "Publications" page. The author, Bill Ross, is a member of our Technical Information Section, and in the article he has done a fine job of defining the problem and outlining means of attack on it. Just what Georgia Tech is doing in this important area of research remains to be said, however, and we believe it is significant. Therefore we are planning a series of feature articles on the subject for the *Research Engineer*. Look for it in the December issue.

adios

• In the publishing business, it is no secret that most of the editing is done by associate or managing editors. For the past eight issues, this magazine has been right up there with the rest of the business, for its production from article conception to the finished product has been carried out by Associate Editor Cecil Phillips, an Industrial Engineering graduate student.

During this period, Cecil has also produced brochures, flyers, and press releases; worked on annual reports; conducted hundreds of people on tours of the Station; developed into an excellent writer and 35mm photographer; assisted on a special research project; and still maintained excellent grades in his graduate work. This month, he picks up his M.S. degree (he received his B.S. in I.E. at Tech in 1955) and heads out for Maryland to join an operations research organization. In the months that we have worked with Cecil, we have seen him grow from a student editor to a polished professional even though he knew that this was not to be his career field. His dedication to a job that was at its best transitory was a revelation in a time of less-than-dedicated people. We are convinced that he has made the best decision in his life in giving up this "rat race" as a career. But we sure hate to see all of that talent and dedication leave Georgia Tech.

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